PB90-134214

Regional Growth Trends of Three Western Conifers as Related to Ozone

(U.S.) Corvallis Environmental Research Lab., OR

1989

U.S. Department of Commerce
National Technical Information Service
NTIS

ERL-COR-1019D

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comple

1. REPORT NO. EPA/600/D-89/214	2.
3.	PB90-134214
4. TITLE AND SUBTITLE Regional Growth Trends of Three Western Conifers as Related to Ozone	5. REPORT DATE
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Greg Reams and Richard K. Olson	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS OSU, Corvallis and NSI, ERL-Corvallis	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS US Environmental Protection Agency Environmental Research Laboratory 200 SW 35th Street Corvallis, OR 97333	13. TYPE OF REPORT AND PERIOD COVERED Symposium Paper
	14. SPONSORING AGENCY CODE EPA/600/2

15. SUPPLEMENTARY NOTES
1989. Proceedings of sympcsium from Air and Waste Management Association Annual Meeting.

16. ABSTRACT

Significant portions of California mixed conifer forests are exposed to and influenced by the large extent of foliar injury. Foliar ozone injury to Jeffrey and ponderosa pine is apparent as far north as Tahoe National Forest and as far south as the San Bernardino mountains east of Los Angeles. Spatial patterns of ozone foliar injury appear to be correlated with spatial patterns of ozone concentration. Decreased ozone injury in the San Bernardinos over the last decade corresponds with decline ozone concentrations over the same time period. Visible injury is not a consistent indicator of changes in growth rate.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 12
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

89-135.2

EPA/600/D-89/214

Regional Growth Trends of Three Western Conifers as Related to Ozone

[1] Gregory A. Reams, [2] Richard K. Olson

[1] Department of Forest Resources, Oregon State University, Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333

[2] Environmental Research Laboratory, 200 SW 35th Street, Corvallis, OR 97333

ABSTRACT

Significant portions of California mixed conifer forests are exposed to and influenced by ozone as evidenced by the large extent of foliar injury. Foliar ozone injury to Jeffrey and ponderosa pine is apparent as far north as Tahoe National Forest and as far south as the San Bernardino mountains east of Los Angeles. Spatial patterns of ozone foliar injury appear to be correlated with spatial patterns of ozone concentration. Decreased ozone injury in the San Bernardinos over the last decade corresponds with decline ozone concentrations over the same time period. Visible injury is not a consistent indicator of changes in growth rate.

INTRODUCTION

Acid deposition and other atmospheric pollutants are considered to be possible contributors to changes in forest condition in some regions of the United States. In the eastern U.S., mortality of high elevation red spruce (*Picea rubens* Sarg.)[1], reduced growth rates of southern pines[2], and changes in soil chemistry in northern hardwoods[3] may be linked to sulfur and nitrogen deposition and increased ozone concentrations.

Forests in the western U.S. as a whole receive lower exposure to pollution than Eastern forests. Wet sulfur and nitrogen deposition rates in the West are 15 - 25% of rates in the East[4]. Although forests in the Puget Sound region[5], Sierra Nevada[6] and Colorado Rockies[7] are exposed to clouds which can be as acidic as Appalachian Mountain clouds on an event basis, the average acidity of the clouds is lower. Dry deposition of sulfur and nitrogen may exceed that in wet deposition in some regions of the West, but data is severely lacking.

There is no evidence of current deleterious effects of sulfur and nitrogen deposition on Western forests. The potential for longer term effects has not been thoroughly evaluated, although Binkley[8] has reviewed existing literature on Western forest soils. He concluded that while some forest soils in the West are sensitive to acidic inputs, they are not likely to be altered by current levels of deposition.

Ozone is the only atmospheric pollutant to which Western forests are exposed at levels similar to or greater than Eastern forests and for which regional effects have been demonstrated. Forested areas commonly exposed to ozone concentrations > 120 ppb include the Puget Sound basin, west slope of the Sierra Nevada, and the San Bernardino and San Gabriel Mountains of southern California[4]. Other forests likely to experience elevated levels of ozone because of their proximity to large urban areas include the Rincon, Catalina and Santa Rita Mountains in southern Arizona and the Front Range of the Colorado Rockies.

Foliar injury to ponderosa pine from ozone was first detected in the San Bernardino mountains of Southern California in the 1950's[9]. Needle damage attributable to ozone has since been observed along the west slope of the Sierra Nevada as far north as Lake Tahoe[10].

A key question is whether forests in areas showing visible foliar damage are also experiencing reduced growth. Reductions in growth of both conifer and hardwood species have been correlated to exposure of air pollutants.[11-14] Visible injury, however, may not be a reliable indicator of growth responses[15,16].

This paper reviews the results of four studies which investigated regional growth trends of selected western conifers. The regions and primary species included in the studies were, (1) west slope Sierra Nevada (ponderosa pine, *Pinus ponderosa* Laws.)[17], (2) west slope Sierra Nevada (Jeffrey pine *Pinus jeffreyi* Grev. and Balf.)[18], (3) San Bernardino Mountains (ponderosa and Jeffrey pine)[14] and (4) south-central Arizona (Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco and ponderosa pine)[19,20]. Each study included sites believed to be exposed to elevated levels of ozone, and comparable sites with presumed lower ozone concentrations. Estimation of visible foliar damage was an integral part of three of the studies, and was conducted on a subset of sites as part of the fourth study.

Study locations and populations of inference

The areas encompassed by each of the four studies are shown in Figure 1. They focus on species within the mixed conifer forests of California and Arizona, and include the forests which receive the highest exposure to ozone in the West (Figure 2)[4].

(1) In a study of ponderosa pine by Peterson et al.[17], a total of 56 sites were sampled to investigate the effects of chronic ozone exposure on ponderosa pine. Site locations ranged from within Sequoia National Forest in the south to Tahoe National Forest in the north (Figure 1) along a presumed gradient of decreasing ozone concentrations (Figure 2a). Site selection was confined to mixed conifer forest stands with ponderosa pines > 50 years old, and only to trees on south, west or flat aspects, on slopes of 0-80% and within elevational limits of 900-2000 m. Trees at the sites were presumably under varying levels of competition, as plot basal areas ranged from 27 to 163 m^2/ha. The western sites were selected for the presence of visible foliar injury from ozone (symptomatic), while trees at the eastern sites lacked foliar injury (asymptomatic). Physical barriers to airflow from the Central Valley were assumed to reduce the exposure of the interior eastern sites to ozone relative to the western sites.

(2) In a study of Jeffrey pine by Peterson et al.[18], five study sites in the western and three sites in the eastern portion of Sequoia and Kings Canyon National Parks were selected. Only study sites with southwest aspects, on slopes of 50-90% and within elevations of 1800-2300 m were selected. Only open grown trees were sampled to reduce possible effects of competition on growth response. Like (1), the western sites were selected for the presence of visible foliar injury from ozone (symptomatic), while trees at the eastern sites lacked foliar injury (asymptomatic).

(3) Miller and others have been investigating the effects of ozone on the mixed conifer forest of the San Bernardino mountains (Figure 1) since 1974[14,21,22]. Because ozone is generally transported from the west to east, a transect of 15 forest plots was established in the same direction across the mountains (Figure 2b). Plot elevations range from 1500 to 2320 m, with each plot being 30 m wide and up to 300 m long, with the length determined on the area required to include at least 50 trees that are larger than 30 cm at breast height. Ponderosa and Jeffrey pine are the primary species evaluated for growth and canopy condition in this study[14].

(4) The fourth study focused on south and central Arizona[19,20] and conducted an extensive survey including a number of different coniferous forest types (Figure 1). 41 sites were sampled, the majority for ponderosa pine (21 sites) and Douglas fir (11 sites). Sites in the Catalina, Rincon and Santa Rita Mountains were selected because their proximity to Tucson likely results in increased exposure of these forests to ozone. Sites on the Mogollon Rim in

Figure 1. Areas encompassing study site locations.

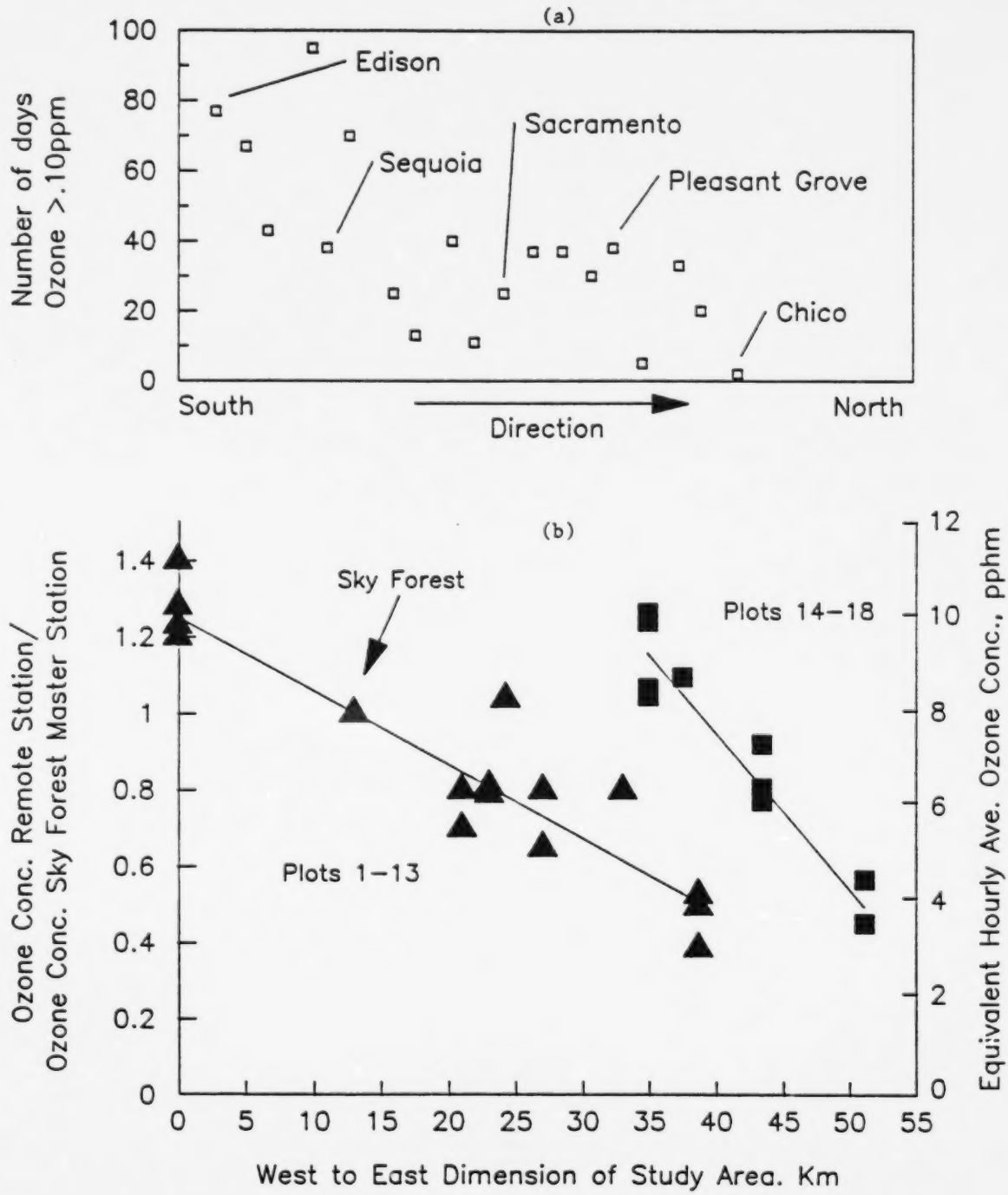

Figure 2(a). Gradient of ozone concentration from south to north in the Central Valley of California. (b) Gradient of concentration along two west to east axes in the San Bernardino Mountains.

central Arizona were assumed to be less polluted. Elevation of sites range from 1500-3000 m. Because the sampling criteria were based on assumed pollutant exposure, and not on specific site characteristics, forest stands selected in these areas vary substantially in slope, exposure, and density (trees/ha).

Foliar Damage Scoring

In all four studies evaluated foliar damage using indices based primarily on visual estimates of needle loss and chlorotic mottling of retained needles[14,17-19,23]. In the Jeffrey and ponderosa pine studies of Peterson et. al.[17,18,23], scoring was done during the single year of each study. In the Arizona study scoring was done in 1987 and 1988[19]. In the San Bernardino study, end of growing season estimates were determined annually from 1974-1978, and in 1988.

Statistical Analysis

Dendrochronological methods were used in the ponderosa and Jeffrey pine studies in the Sierra Nevada[18-20] and in the ponderosa and Douglas fir study in Arizona[21,22]. Fundamental to dendrochronology is the accurate crossdating of tree cores. Crossdating is the assignment of each annual ring to a specific year. This is necessary so that the temporal covariation of tree-ring response and environmental influences can be investigated accurately. If tree-ring series are not reliably crossdated, then the matching of time-related environmental variables with tree-ring response is not possible. In the above studies only those cores that could be confidently crossdated were analyzed.

In the two dendrochronological studies in California, two cores per tree were extracted at breast height from at least 25 dominant, codominant or intermediate trees[17,18]. In the Arizona study two cores per tree were extracted at breast height from 15-25 dominant or codominant trees[19,20] Ring widths were measured to the nearest 0.01 mm and then crossdated. The time series for each tree was then standardized and converted to tree-ring indices, which represents radial growth on a relative scale. Standardization removes the biological growth trend and thus allows comparison of radial growth patterns among trees of different size, age and rate of growth. All of the dendrochronological studies used differing detrending techniques. It is beyond the scope of this paper to discuss all the possible ramifications of the various techniques and suggest which are best, this is an area of continuing research and discussion.

The response of tree-ring indices to climate was investigated by matching prior and current year, monthly climate data from nearby weather stations, with a mean value function for the index chronology at each site. Results from regression analyses indicate that the best predictor for the Arizona study was the sum of precipitation from prior August to current year July. For the Sierra Nevada studies two variables were consistently correlated with growth; winter precipitation (October to March) and summer temperature (July to September)[17,18]. Tree-ring response was positively correlated to precipitation for all studies, and negatively correlated to summer temperature for the Sierra Nevada studies.

For each dendrochronological study, predictive relationships between tree growth and climate were used to estimate growth for a pre-pollution and pollution era[17-20]. The goal is to compare pre-pollution climate-tree growth response to growth response in a recent time period considered polluted. The logic is that pollution induced stress can lead to disruption of normal physiological activity, and the normal relationship between climate and tree-growth may change. For the Arizona study 1961 is used as the pre-pollution cutoff date, and for the Sierra Nevada studies 1965.

The San Bernardino study[14] used simple linear models to investigate the correlation of ozone injury and winter precipitation with diameter growth response of individual ponderosa and Jeffrey pine trees. Growth calculations were based on individual tree measurements of diameter at breast height. Diameters were measured to the nearest 0.1 cm in 1974, 1978, 1983 and 1988.

Results and Discussion

Foliar Ozone Injury

Injury to ponderosa and Jeffrey pine from ozone as evidenced by needle loss and ozone chlorosis is widespread in the mixed conifer forests of both the San Bernardino Mountains and the Sierra Nevada. In six of fifteen plots in the 1988 San Bernardino study, ponderosa pine had average foliar damage rated moderate to severe[14]. All ponderosa pine plots showed some foliar damage.

There is an ozone injury gradient to ponderosa pine in the Sierra Nevada, which parallels a presumed ozone exposure gradient[10,24-26], with greatest injury and ozone concentration in the southern Sierra and the least in the northern Sierra[17,18]. All studies in the Sierras and San Bernardinos on ponderosa and Jeffrey pine found that foliage injury was greatest in the west and decreased progressively eastward.

A west to east decrease in foliar injury suggests a concomitant decrease in ozone concentration in the Sierras. A west to east trend was documented in the early 1980's in the San Bernardinos[27]. The west to east gradients of the 2 study areas may differ in that foliar injury in the San Bernardinos indicates a gradual change while in the Sierra Nevada the gradient of foliar damage is much sharper, with the west slopes having high injury and the interior sites almost none. In the San Bernardinos distance from the western ozone sources and elevation vary simultaneously, thus ozone injury decreases with increasing elevation.

In the San Bernardinos, there has been an approximate 20% reduction since 1974 for both the average monthly maximum ozone concentration and the 24-hour average monthly ozone concentrations for May through October. Remeasurement of previously sampled Jeffrey and ponderosa pine at all but 2 of the 15 sites have shown a marked improvement in foliar injury over the same time period. The 2 sites showing no improvement are located at the western most boundary of the study where ozone concentrations are the highest[14].

Foliar ozone damage was surveyed at a subset of the survey sites representing high and low ozone exposure in Arizona. Foliar ozone injury was observed only at sites within the Rincons (high exposure), where 11 out of 37 ponderosa pine trees sampled have slight chlorotic mottle attributable to ozone. Foliage evaluation of 34 southwestern white pines (*Pinus strobiformis*), 11 Douglas firs and 10 white firs (*Abies concolor* Lindl.) in the Rincons indicate no evidence of ozone damage[19].

Growth Trends

Jeffrey Pine

Radial growth index values were similar for symptomatic and asymptomatic sites prior to 1965. Comparison of index values by age class indicates that growth of symptomatic trees was less than that of asymptomatic since 1965 (the assumed period of increased ozone exposure). Trees greater than 100 years old appear to have a greater reduction than younger trees.

Parameter estimation for the dendroclimatic model indicates that winter precipitation accounted for the largest proportion of variance in growth. Climatic variables accounted for less variation in growth index prior to 1955. Since 1955, climate accounted for a larger proportion of growth variation of symptomatic trees but not for asymptomatic trees. Ozone injured trees apparently are more sensitive to interannual variation in precipitation and temperature in the most recent years. This may be an indication that ozone injured Jeffrey pine trees are now more sensitive to climate.[20]

Ponderosa Pine

There appears to be no large-scale regional reduction of ponderosa pine tree growth in the Sierra Nevada. Stands showing increased growth outnumber those showing decreases (11 vs. 6). There is no correlation between decreased growth and location of the stands along the ozone gradient. Stands with decreased growth were located throughout the north-south range of the Sierra Nevada and among symptomatic and asymptomatic sites. The lack of correlation between growth and ozone injury contrasts with the correlation demonstrated for Jeffrey pine in an earlier study[17,18].

Growth rates appear to be associated with disease, management practices and with the exception of some southern symptomatic sites, precipitation pattern. Previous to the 1950's, the southern symptomatic sites show a positive correlation between growth and winter precipitation. The lack of correlation since the 1950's at these southern sites may be an indication of more severe ozone injury.

In the San Bernardino Mountains[14], ponderosa and Jeffrey pine growth rates for the period 1984-1988 have shown, based on average stem increment per plot, nearly equal cases of increases and decreases relative to growth during 1979-1983. Stand growth was not correlated with stand ozone injury index. Within stands, however, growth of individual trees was correlated with degree of foliar ozone injury. Differences in soil moisture availability among stands overrode the probable influence of ozone damage on stand growth.

In Arizona comparisons between observed and expected growth from 1961-1986 indicate that 5 of 8 sites in the south (higher potential pollution) and 3 out of 13 sites in the north show growth reductions[19]. A comparison of the frequency of declines (based on the number of sites) between the two regions yields a Fisher's exact value of 0.09, which is near the critical range and therefore suggestive of a difference. However the only ponderosa pine to show ozone damage on foliage are trees located in the Rincon Mountains. All 3 sites in the Rincons show growth decreases. Comparing the frequency of declines in the Rincons with the northern sites yields a Fisher's exact probability of 0.0357, which can be interpreted as highly suggestive of a decline in the Rincons. While air pollution is one possible explanation for this decline, among tree competition in these stands may also be reducing growth rates.

Douglas Fir

The small number of Douglas fir stands sampled in the Arizona study[19] make it difficult to demonstrate significant growth differences between southern and northern areas of the study. However, 5 of 7 (71%) in the south showed less than expected growth rates for 1951-86, while only 1 of 4 stands in the north showed reduced growth for this period. A comparison of the decline frequencies between the north and south, using a Fisher's exact test indicates a probability of 0.1818. As with the ponderosa pine stands in this study, south/north differences in Douglas fir growth could be attributable to greater among tree competition in some stands as well as to differences in air pollution exposure.

Conclusions

(1) Significant portions of California forests are influenced by ozone as indicated by the wide extent of foliar damage.

Foliar ozone injury to Jeffrey and ponderosa pine is apparent as far north as Tahoe NF and as far south as the San Bernardino mountains east of Los Angeles. Damage is moderate to severe over large areas of the San Bernardino and southern Sierra Nevada Mountains.

(2) Visible foliar injury may be a useful indicator of relative ozone exposure.

Patterns of foliar injury correspond to presumed south-north and west-east gradients of ozone concentration in the Sierra Nevada and San Bernardino Mountains. In addition, trees in the San Bernardinos have shown a decrease in foliar injury that corresponds with a decline in ozone concentrations over the same time period. All correlations, however, are weakened by the limited ozone data available at forested sites.

(3) Visible foliar injury is not a consistent indicator of changes in growth rates.

Foliar ozone injury has been associated with radial growth reduction of Jeffrey pine in Sequoia and Kings Canyon National Park. Larger and older trees have greater reductions in growth, while younger trees did not show a growth reduction.

Ponderosa pine on symptomatic sites in the Sierra Nevada have not shown a regional trend towards decreased growth. There are, however a few symptomatic sites in the southern Sierra that have growth decreases since the 1960's.

In the San Bernardino Mountains, growth rates of individual ponderosa and Jeffrey pine trees within stands are correlated with degree of foliar damage. Differences in growth among stands are not correlated with canopy damage, but rather with soil moisture availability.

In Arizona, there are insufficient data to correlate possible growth declines in ponderosa pine and Douglas fir with foliar damage.

(4) Ozone injury to foliage of forest trees over large acreages is unique to the western U.S. and especially southern California. Growth studies in the southern Sierra Nevada and San Bernardino mountains, although open to interpretation, suggest ozone is reducing Jeffrey and ponderosa pine growth rates in some areas. The broad extent of foliar damage combined with evidence of local growth reductions from ozone exposure represents a response of forests to air pollution that is unparalleled in the United States.

References

1. A.H. Johnson and T.G. Siccama, "Acid deposition and forest decline," *Environ. Sci. Technol.* 17:7:294A. (1983)

2. R.M. Sheffield, N.D. Cost, W.A. Bechtold and J.P. McClure, "Pine growth reductions in the Southeast," USDA Forest Service Res. Bull. SE-83. (1985)

3. M.B. David, D.F. Grigal, L.F. Ohmann and G.Z. Gertner, "Sulfur, carbon, and nitrogen relationships in forest soils across the northern Great Lakes States as affected by atmospheric deposition and vegetation," *Can. J. For. Res.* 18:1386 (1988)

4. M. Bohm, "Regional characteristics of air quality in the coniferous forests of the western United States," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

5. F.A. Basabe, W. Chang, T.V. Larson and R.L. Edmonds, "Fog and cloud water chemistry in western Washington," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

6. P.S. Muir and M. Bohm, "Cloud chemistry and occurrence in the western United States," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

7. D.F. Miller and R.D. Borys, "Chemistry of summer cloud, rain and air at a Rocky Mountain-top location," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

8. D. Binkley, "Sensitivity of forest soils in the western U.S. to acidic deposition," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

9. P.R. Miller, J.R. Parmeter, O.C. Taylor, E.A. Cardiff, "Ozone injury to foliage of *Pinus ponderosa*," *Phytopathol.* 53:1072 (1963).

10. J. Pronos and D.R. Vogler, "Assessment of ozone injury to pines in the southern Sierra Nevada, 1979/1980", USDA For. Serv. Pac. SW Region Forest Pest Manage. Rep. 81-20, 13pp.

11. J.R. Parmeter, P.R. Miller, "Studies relating to the cause of decline and death of ponderosa pine in southern California," *Plant Dis. Rep.* 52:707 (1968).

12. S.O. Phillips, J.M. Skelly, H.E. Burkhart, "Growth fluctuation of loblolly pine due to periodic air pollution levels: interaction of rainfall and age," *Phytopathol.* 67:716 (1977).

13. L.J. Puckett, "Acid rain, air pollution, and tree growth in southeastern New York," *J. Environ. Qual.* 11:376 (1982).

14. P.R. Miller, J.R. McBride, S.L. Schilling, A.P. Gomez, "Trends of ozone damage in conifer forests in southern California," *JAPCA* (1989) (in press).

15. P.B. Reich, "Quantifying plant response to ozone: a unifying theory," Tree Physiology 3:63 (1987)

16. D.M. Ewell, L.C. Mazzu and D.M. Duriscoe, "Assessment of ozone injury effects on ponderosa pine productivity with specific leaf weight," Proceedings 82nd Annual Meeting of AWMA, Anaheim, California, June 26-30, (1989)

17. D.L. Peterson, M.J. Arbaugh, L.J. Robinson, "The effects of ozone stress on tree growth and vigor in the Sierra Nevada of California, USA," in *Proceedings IUFRO Symposium on Air Pollution and Forest Decline*, Interlaken, Switzerland, 2-7 October, (1988) (in press).

18. D.L. Peterson, M.J. Arbaugh, V.A. Wakefield, P.R. Miller, "Evidence of growth reduction in ozone-injured Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) in Sequoia and Kings Canyon National Parks," *JAPCA* 37:906 (1987)

19. D.A. Graybill, M.R. Rose, "Analysis of growth trends and variation in conifers from central Arizona," Annual Report, Western Conifers Research Cooperative, ERL-Corvallis. (1989).

20. D.A. Graybill, M.R. Rose, "Analysis of growth trends and variation in conifers from Arizona and New Mexico," *JAPCA* (1989) (in press).

21. P.R. Miller, "Ozone effects in the San Bernardino National Forest," in *Proceedings of the Workshop on Air Pollution and the Productivity of the Forest*," Izaak Walton League of America, Arlington, VA. pp. 161-197. (1983)

22. J.R. McBride, P.R. Miller, R.D. Laven, "Effects of oxidant air pollutants on forest succession in the mixed conifer forest type of southern California," in *Proceedings of the Symposium on Air Pollutants Effects on Forest Ecosystems*, Acid Rain Foundation, St. Paul, MN, pp. 157-167. (1985)

23. P.S. Muir, T.V. Armentano, "Evaluating oxidant injury to foliage of *Pinus ponderosa*: a comparison of methods," *Can. J. For. Res.* 18:498 (1988).

24. J.R. Allison, "An evaluation of ozone injury to pines on the Eldorado National Forest," USDA For. Serv. Pac. SW Region Forest Pest Manage. Rep. 84-16, 10pp. (1984)

25. J.R. Allison, "An evaluation of ozone injury to pines on the Tahoe National Forest," USDA For. Serv. Pac. SW Region Forest Pest Manage. Rep. 84-30, 10pp. (1984)

26. D.R. Vogler, "Ozone monitoring in the southern Sierra Nevada, 1976-1981," USDA For. Serv. Pac. SW Region Forest Pest Manage. Rep. 82-17, 43pp. (1982)

27. P.R. Miller, O.C. Taylor, R.G. Wilhour, "Oxidant air pollution effects on western coniferous forest ecosystems," Environ. Research Brief. U.S. Environmental Protection Agency, Washington, D.C. (1982)

28. P.R. Miller, "Oxidant induced community change in a mixed conifer forest," in *Air Pollution Damage to Vegetation*, J.A. Naegele (ed), *Advan. Chem. Ser.* 122:101 (1973)

29. D.L. Peterson, M.J. Arbaugh, "Growth trends in the mixed conifer forest of the Sierra Nevada," Final Report, Western Conifers Research Cooperative, Forest Response Program, ERL-Corvallis, Oregon. (1988)